Experimental Study of Local Scour Around Elliptic and Semi-parabolic Groynes in Straight Channels

Ali khairi Ibrahim
College of Engineering- Baghdad University
Email: ali_200n@yahoo.com

Dr. Hayder A.K. AL-Thamiry
College of Engineering- Baghdad University
Email: dr_hydr@yahoo.com

Abstract: -

This study was carried out to investigate local scour around curved groynes under different conditions including flow condition, average values of radius of curvature, spacing between groynes, width of groynes, number of groynes, and shapes of groynes. Laboratory works were achieved with 300 runs for elliptic and semi-parabolic groynes models. Three different widths of groynes were adopted as (7, 10, and 13 cm), as well as, using three different number of groyne, single, double and triple. Four different spacing between groynes of (1, 1.5, 2, and 2.5) times of width of groyne were used in the study. The average values of radius of curvature for all adopted shapes used was computed as an additional significant parameters. Dimensional analysis techniques and (MATLAB V.13) program were used to detect the two dimensionless formulas of maximum scour depth for elliptic and semi-parabolic groynes. The results gave good determination coefficient of (99) % for both formulas. Generally, the elliptic groyne is the best case of all groynes because gives minimum scour depth, minimum volume of scour and transition of sediments.

Keywords: Local scour, Groynes, Elliptic, parabolic, curvature.

1 Introduction

Erosion of the banks beds of manmade and natural channels are common problem facing water resources management. Groynes are the most common structures found in treating problems of bank erosion. They have been known as hydraulic structures extending at some angle, perpendicularly, or outward from the bank stream into the streamline. They are used for many purposes; protecting the bank against erosion, reducing the velocity of flow along river banks, owing to their roughness, maintaining the navigation channels and controlling the flow into or out of a bend through meandering channel [5]. Scour is a normal condition as a result of water movement in channels and streams. It is caused by the erosion process of flowing water, that separating material and moves it from the bed and banks of rivers [1]. Scour around groyne can cause serious problems, such as weakening structural stability [2]. Groynes are a hydraulic structure installed at an angle toward or reverse the flow of the river in order to keep high water currents away from the critical areas of the river. The main goal of this structure is to protect riverbanks from erosion and control flooding and improve navigation work and maintain the desired channel shape [12].

2 Review of Literature

[13] based of search, principles mechanism of local scour and find out effect parameters on maximum of scour depth and style of scour vicinity groynes, which including flow depth, Froude number, water depth, opening ratio, Angle of spur-dike inclination, and Operating time.[7] based of study for find out the maximum scour depth in all experiments is directly proportion to Froude number and inversely with inclination angle groynes. [8] test various cases of groynes in dimension and angle inclination. The main targets, which were based upon experiments were to assess the effect of different angles on the amount of scour and possibility of water habitats and reduce erosion neighboring to the stream bank. Concluded that the angle inclination of groyne with 45° would be a big bed erosion, instability, it also showing that the angle inclination of groyne with 135° had have greatest amount of scour hole in tests. Finally, it was found that the groyne associated with 135° considered best because it given senior local scour and minimal bed erosion in the channel bank. [9] investigate effect inclination angle of groynes on exchange process of water mass in the dead zone in the flume using different engineering position for fields of groyne. Noted by results that the exchange percentage of water mass for groynes (25 cm) length was smaller than groynes (50 cm) length with same value of ratio (width and length) for both cases. [3] indicated of study investigate local scour around a single submerged spur-dike through important factors a significant impact on the scour hole characteristics of spur-dike that including flow parameters, contraction ratio (b/B), and alignment angle. Noted that main reason in increasing in scour process is horseshoe vortex. [6] indicated the flow effect around the refraction groynes because of mutations in the arm angle (θ) and length (AL). Experimental results were analyzed depended on the effects of the refraction groynes coinciding with projection length (L'). The recirculation area was created in the domain (26 – 47) % of the river width. As well as, the recirculation area in the downstream (URG) was more than that of (DRG). So, DRG is more advantage than URG in expressions of flow change, velocity water, and local vortex erosion. [10] concluded of study to investigate the local around a bell mouth groynes structure under clear water conditions in straight channel. He observed that maximum scour depth increases with flow intensity and Froude number. The relationship between maximum deposition and maximum scour was

linear with slope less than 1, the depth of deposition is always less than depth of scour.

[2] depended the study on laboratory experiments to compute the maximum depth of local scour around groyne. Using different number (single, double and triple) with different shape (straight, T-head and L-head). The different type of spacing using in study (1, 1.5, and 2) times from vertical height of projected groynes. Estimated relationship between maximum scour depth and flow parameters, and also, noted from results that greatest depth of scour was with groyne (L- head) and gradually less with groyne (T-head) and then more less with groyne (straight).[4] based of the study was laboratory experimental to evaluation of local scour development around curved impermeable groynes. Using same hydraulics characteristics with [2] but two shapes of curved groynes using in the study (semi-parabolic and quadrant). Concluded that maximum scour depth increases directly proportional to increases length of groynes, while decreases with decreasing spacing between groynes and noted that quadrant shape gave less depth scour than semi-parabolic shape.

3 Objectives

The main goals of this research are to study the basic mechanism of local scour and assess the main active parameter which controlling on scour volume around groynes by investigate the effectiveness and how efficient of using different shapes, heights, and numbers of groynes (single, double and triple), with different spacing between them, depth of flow, Froude number, and average value of curvature, and addition, Find dimensionless formula represented by laboratory data relating to scour depth and related variables with the help of dimensional analysis and program of statistic.

4 Methods and Material.

This section includes a description of the apparatus used and the method of data extraction, use of variable forms of curved groyne and the creation of a formula based mainly on the dimensional analysis.

4-1 The Experimental Work

Laboratory experiments were conducted on the flume has rectangular cross section, 6.6 m length, 0.4 m width, and 0.4 m depth, under steady subcritical flow, clear-water condition and uniform cohesionless sand as bed material. Generally, the flume is divided into three main parts, the first part is called inlet tank enters the water to it through a tube coming from the pump, the second part is represents the working section that including sharp crested rectangular weir, dispersers of energy, and sand layer. The last part of flume is a main reservoir that accumulates water coming from the working section. Each depths of experiments, measured by using a point gauge with accuracy (±1) mm which can move easily over the working section in both directions vertical and horizontal. Every experience is running about 4 hours continuously as maximum to achieve scour stability and to avoid influence of the time factor on the scour process.

4-2 Modeled groynes

The models used in this study are made of foam material. In general, the thickness and height of model were 10 mm and 20 cm respectively, either length varies depending on the purpose to be studied. Also, chosen two types of curved groynes are namely Semi-parabolic about x-axis and Elliptic groynes with taking into consideration that both types have similar dimensions. As shown in **Fig. 1**.

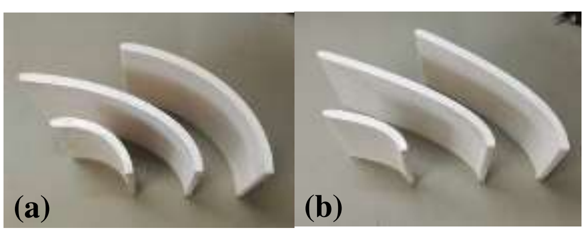


Fig. 1 (a) Elliptic (b) Semi-parabolic.

4-3-Dimensional Analysis

The essential goal of this research program was to calculate the scour depth (ds) by dimensional analysis technique at a groyne nose, taken into consideration function of the following parameters as shown in Eq 1 and as shown in **Table. 1**

$ds = f\{y, v, vc, W_g, C_{av.}, \rho, \rho s, g, n, b, D_{50}, \mu, \boldsymbol{\sigma_g}, B, S_0\}$ 1

The equation 1 can be written as:

$ds/y = f(v/vc, W_g/y, C_{av.}/y, \rho_s/\rho, Fr, n, b/y, D_{50}/y, Re, \boldsymbol{\sigma_g}, B/y, S_0)$ ….…..... 2

As flume width is constant (40 cm) for all runs, it can be disregarded B/y. Effect of changing flume width is implicitly considered in v/vc. Simplifying the equations above and eliminating the parameters with constant and negligible values, and applying the assumption (single sediment size, effect of viscosity and relative density). Equation 2 can be written as:

$ds/y = f(v/vc, W_g/y, Fr, b/y, n, C_{av.}/y)$.....3

Table. 1 The basic parameters to finding approximately equation of scour depth.

Flow characteristics		
Variable	Definition	Dimension
y	Flow depth	L
v	Mean approach flow velocity	LT^{-1}
V_c	Critical velocity	LT^{-1}
g	Gravitational acceleration	LT^{-2}
Sand properties		
ρ_s	Sediment density	ML^{-3}
D_{50}	Median particle grain size	L
σ_g	Geometric standard deviation	-
Water properties		
ρ	Water density	ML^{-3}
μ	Dynamic viscosity of water	$ML^{-1}T^{-1}$
Models properties		
$C_{av.}$	Av. radius of curvature	L
W_g	Width of Groynes	L
n	Number of Groynes	-
b	Spacing between Groynes	L
Flume properties		
B	Width of flume	L
S_0	Slope of channel	-

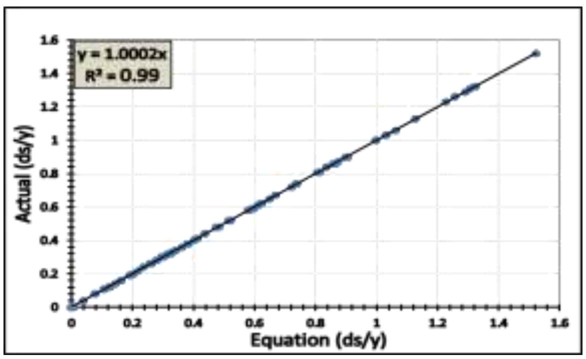
The formula was developed by using the computer package (MATLAB V.13) to analysis the results. Equation (4) is listed below and its coefficients are illustrated in **Table 2**

$$d_s/y=C_0+C_1*(v/vc) + C_2*(W_g/y) + C_3*Fr + C_4*(b/y)+C_5*n+C_6*(C_{av.}/y)+R. \quad .... (4)$$

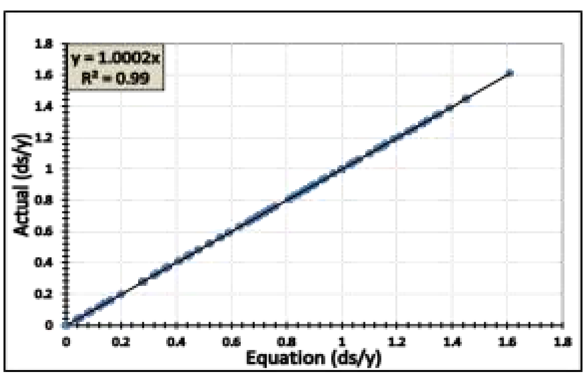
Table. 2 The coefficients of equations with two both shapes.

Shape	C_0	C_1	C_2	C_3	C_4	C_5	C_6
Elliptic	-1.1453	-3.8573	0.2212	8.9643	0.0168	-0.0693	-0.0433
parabolic	-2.8091	5.1347	0.2701	1.6234	0.0057	-0.0879	-0.0351

The values of $\mathbf{R^2}$ are given a well fitness for all data and both formulas as shown in **Fig. 2.**



A- Elliptic groynes



B- Semi parabolic Groynes

Fig. 2 Comparison between d_s/y calculated by equation (4) and d_s/y measured by experiment for semi-parabolic groyne.

5 Results and Discussion

Results of laboratory experiments are concentrated on describing the effect of main parameters (average values radius of curvature and width of groyne, number of groynes, and spacing between groynes, Froude number, and shape of groynes) on scour volume. Several curves have been drawn to indicate the nature of the relationship between scour volume and the causing factor in occurrence scour.

5-1 Spacing between Groynes

Spacing between groynes have significant effect on scour process and the transports of sediment. Groyne spacing depended on average value radius of curvature and horizontal distance of groynes (W_g).

Fig. 3 illustrate the effect of spacing between groynes on the amounts of scour. Four different spacing were used with two and three groynes to identify the reality of this effect. The volume of scour is directly proportional with increasing of spacing between groynes ،the reason is that the minimum flume width is located at the tip of groyne, the applied discharge generated a high velocity which lead to increase the process of transport of sediment and formation of scour at downstream of groyne.

When there is available sufficient spacing between groynes reduces the influence of groynes on the flow pattern and leading to transport the sediment formation to the next groyne, this phenomenon is repeating with second and third groyne.

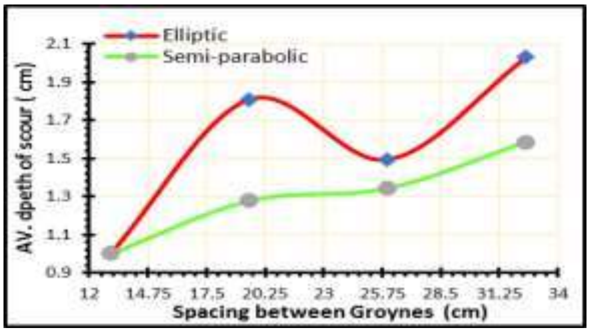


Fig. 3 Variation of average depth of scour with spacing between groynes at spacing b=2.5 Wg, Fr=0.42, and Wg=13 cm.

5-2 Froude Number

It is of great significance, but is barely the most important parameter in the control mechanism scour and movement of sediment. It has been found that Froude Number is directly proportional to flow velocity and scour volume when other parameter is constant, and it inversely proportional to flow depth when the velocity is constant. **Fig. 4** shown a relationship between Froude numbers with average depth of scour.

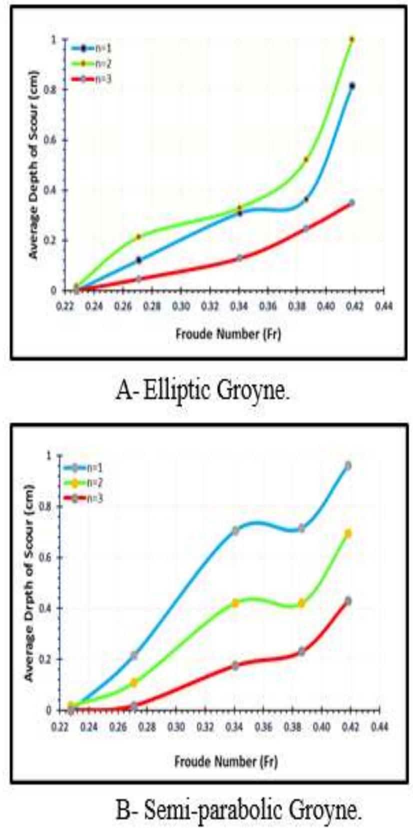
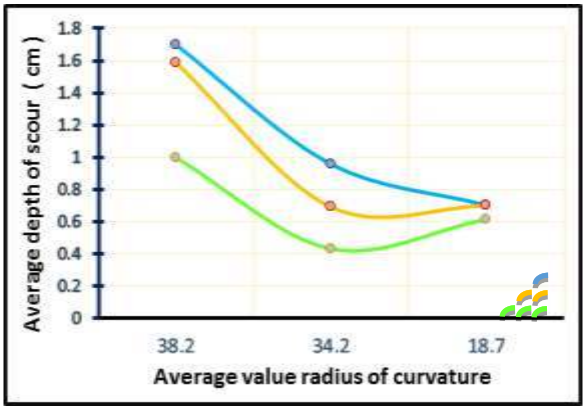


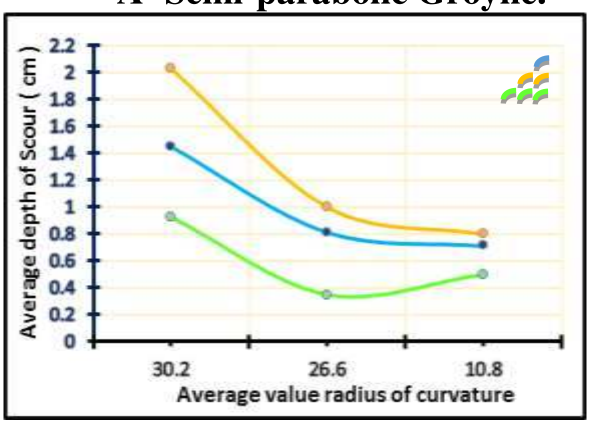
Fig. 4 Effect Froude Number on average depth of scour at different number of groynes with spacing between groyne b=2.5 Wg, and width of groyne Wg=10 cm.

5-3 The curvature

The curvature is considered from main factors which limited volume of scour and transport of sediment. **Fig. 5** shows the relationship between average value radius of curvature and average depth of scour, which showed that the average depth of scour increases with increasing curvature at number of groynes (n = 1, 2). It was found that the lowest value of average depth of scour was at the width of groynes (W_g) = 10 cm, number of groynes (n) = 3 because the flow was smoothly, freely, and average value radius of curvature somewhat nearest for average value radius of curvature rate at groyne (W_g=13 cm) for both types. Average depth of scour defined as product of dividing the scour volume on surface area for formed shape.



A- Semi-parabolic Groyne.



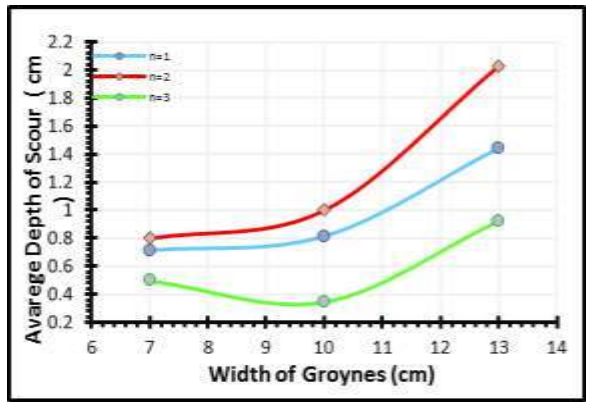
B- **Elliptic Groyne**.

Fig. 5 Effect average value radius of curvature on average depth of scour with at different number of groynes with spacing b =2.5 Wg, and Wg=13 cm.

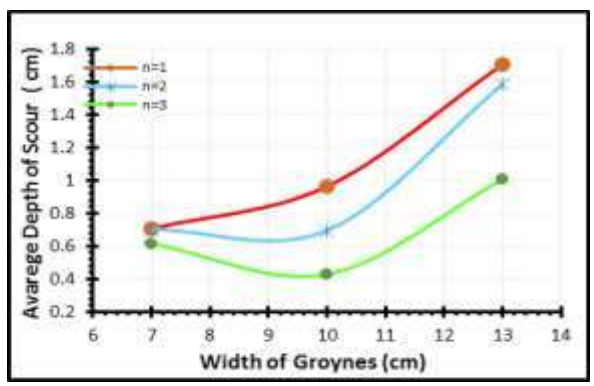
5-4 Width of Groynes

Width of groynes plays an important role in control scour volume and transport of sediment.

Fig. 6 shows the relationship between average depth of scour and width of groynes. It is observed that the scour increases with width of groyne. The reason is that the opening ratio that defined as ratio the net width of flow to the total width of the flume. The opening ratio at the groynes tip has reached to less value. Resulting in the occurrence high velocities at this contraction that leads to increased scour and transports of sediment.



A-Elliptic Groyne.

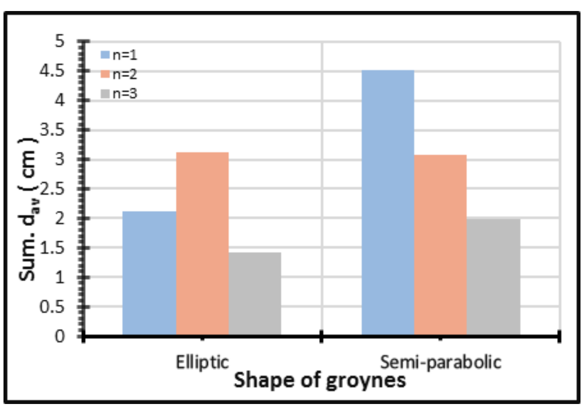


B- Semi-parabolic Groyne.

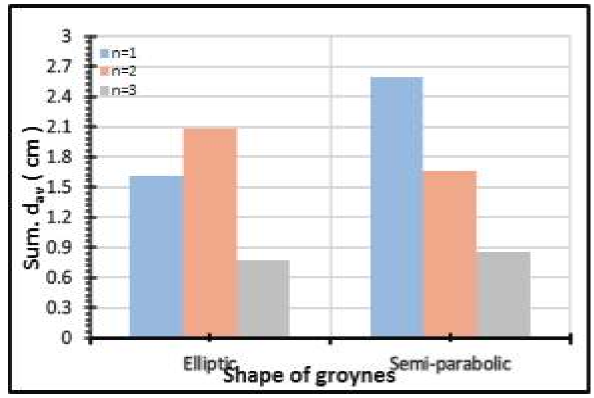
Fig. 6 Effect width of groyne on average depth of scour at different number of both types with spacing b=2.5 Wg, and Fr=0.42.

5-5 Shape of groynes

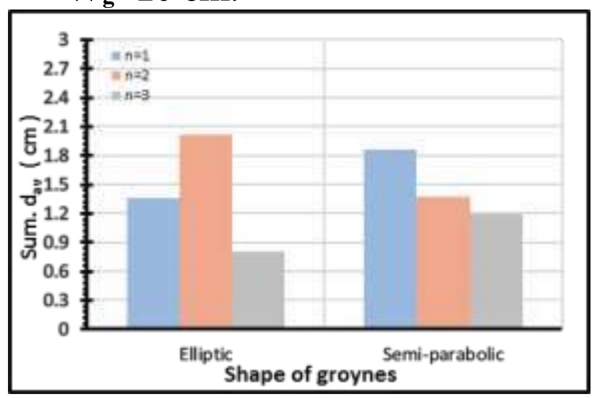
Shapes of groynes are one of the parameters that are no less important than the rest of the factors affecting on the features scour. Although scour volume directly proportional to the number of groynes, but this case is quite different with a sum average depth of scour. For semi – parabolic groyne, the sum. average depth of scour is inversely proportional to groyne number because the formed surface area and volume of scour are increasing with increasing the groyne number with keeps the rest of the parameters constant, while in elliptic groyne, the maximum value of the summation average depth of scour is found at n = 2 explanation of that is which the formed surface area was less than the scour volume in this case. Same process occurs for the different widths of groynes (13 cm, 10 cm, and 7 cm) as shown in **Fig. 7**



A- **Effect of groynes shape at W_g=13 cm**.



B- **Effect of groynes shape at W_g=10 cm**.

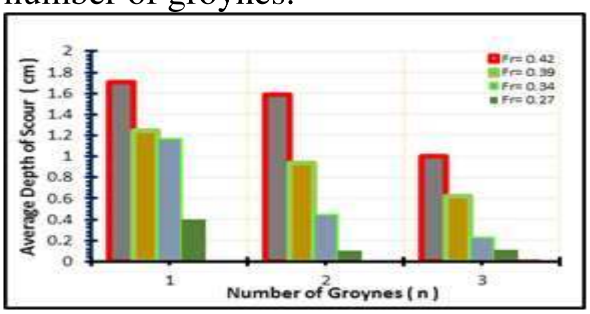


C- **Effect of groynes shape at W_g=7 cm.**

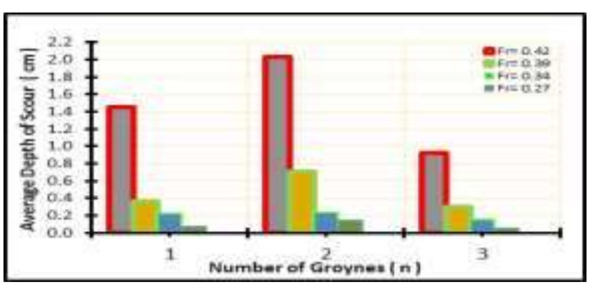
Fig. 7 Variation of summation average of scour depth with shape of groynes at different number of elliptic, semi-parabolic groynes at spacing between groyne b=2.5 W_g.

5-6 Number of Groynes

The relationship between average depth of scour and the groynes number is illustrated in **Fig. 8.** In single groyne, the maximum depth of scour and surface area are greater than double and triple groynes of same shape. At double groynes, the maximum scour volume was at first groyne because there is interfere between scour and sedimentation at the time. Also, the greatest accumulation of sediments located at downstream second groyne, triple groynes, same specifications of double groynes plus middle groyne are influenced by first groyne and it affects last groyne. Generally, scour zone was determined at downstream of the first groyne toward downstream of flume except the elliptic groyne of (W_g=13cm) it starts occurring from the beginning of the first groyne to the last one. **Fig. 9** show that the maximum scour occurs at downstream of the first elliptic and parabolic groynes But, the maximum accumulated sediments were noticed at downstream of last groyne for any number of groynes.

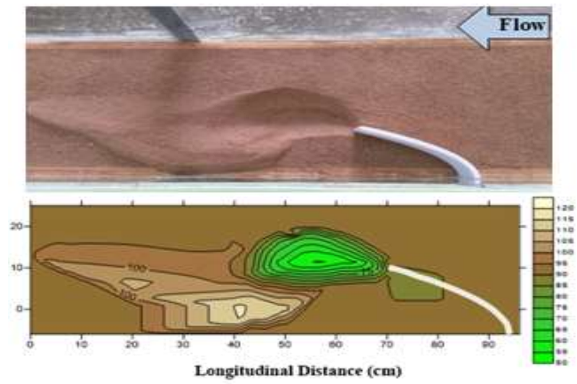


A- Elliptic Groyne.

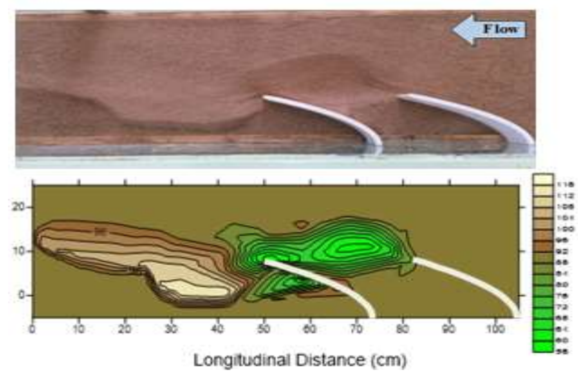


B- Semi-parabolic Groyne.

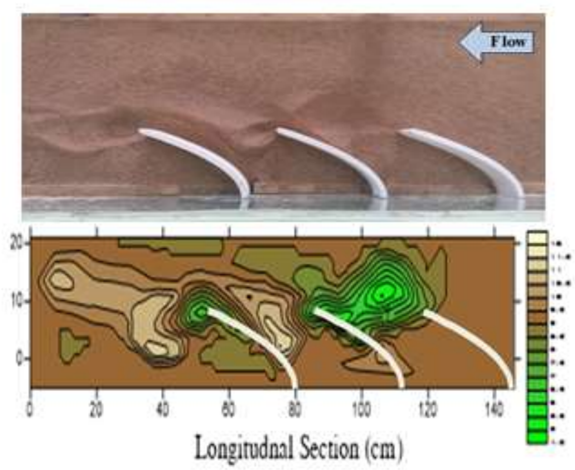
Fig. 8 Effect groyne number on average depth of scour at different Froude number with spacing between groyne b=2.5 Wg and width of groyne Wg=13.



A- Single Groyne.



B- Double Groyne.



C- Triple Groyne.

Fig. 9 Effect of number of groynes on volume of scour caused by semi- parabolic groyne at Fr= 0.39, b= 2W_g, and W_g=13cm.

6 Conclusions

1. The maximum scour depth is observed at downstream of any shape of single curved groyne.
2. The scour volume is directly proportional to the Froude Number, flow depth, and width of groynes for the same number of groynes.
3. The scour volume is directly proportional to the Froude Number, flow depth, and width of groynes for the same number of groynes.
4. Generally, the largest accumulation of sediments is at the downstream of the last groyne.
5. The elliptic groynes of any curvature give minimum scour and deposition comparing with all other shapes of groyne along the effect zone in the laboratory flume.
6. The dimensionless formulas of maximum scour depth for elliptic and semi-parabolic shapes gave good determination coefficient of (99%).So, can be used to find the maximum scour depth for similar condition.

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الدراسة المختبرية للانجراف الموقعي حول المسننات ذات شكل قطع ناقص وقطع مكافئ في القنوات المستقيمة.

علي خيري ابراهيم الجدة
كلية الهندسة- جامعة بغداد
Email: ali_200n@yahoo.com

دكتور حيدر عبد الامير خضير الثامري
كلية الهندسة- جامعة بغداد
Email: dr_hydr@yahoo.com

الخلاصة:-

تم تنفيذ هذه الدراسة لتحري عمق الانجراف الموقعي حول المسننات المقوسة, حيث اجريت هذه الدراسة تحت ظروف مختلفة تشمل حالات الجريان ومعدل قيمة نصف قطر التقوس للاشكال المستخدمة (القطع الناقص والقطع المكافئ) وعدد وعرض المسننات والمسافة الفاصلة بينهم بالاضافة الى شكل المسنن.

هذه العوامل ذات تاثير واضح على تكوين حجم الانجراف الموقعي وانماط الجريان حول المسننات لذلك تم التركيز عليها باعتبارها احد الاهداف الرئيسية للبحث.

اجريت جميع التجارب على قناة ذات مقطع مستطيل الشكل بطول 6.6 متر وعرض 0.4 متر وارتفاع 0.4 متر وتم تصنيع اشكال مختلفة من المسننات القطع الناقص والقطع الكافئ من مادة الفوم والخالية من الرسوبيات المحمولة (Clean-water conditions) وباستخدام تربة كمادة للقاع تمتلك حبيبيات منتظمة الشكل وغير متماسكة.

كانت المسافات الفاصلة بين المسننات ذات تاثير واضح في التجربة فاستخدمت انواع مختلفة منها (1 , 1.5 , 2 , 2.5) كنسبة من عرض المسنن ولوحظ انها تتناسب عكسيا مع التداخل الحاصل بين انماط الجريان بينما تتناسب طرديا مع كمية الانجراف الناتجة منها.

استخدمت تقنية التحليل البعدي وبرنامج MATLAB لايجاد معادلتين لابعدية لحساب عمق الانجراف الموقعي للمسنن القطع الناقص والقطع المكافئ حيث اشتقت معادلة وضعية لحساب اقصى عمق للانجراف الموقعي ولوحظ من خلال مقارنة النتائج المختبرية مع النتائج المستخرجة من المعادلة بانها اعطت توافقا عالي بحيث وصل معامل التحديد (Determination Coefficient) الى 0.99. عموما اعتبر الشكل قطع الناقص افضل حالة من كل انواع الاشكال للمسننات المستخدمة لانه يعطي اقل عمق للانجراف الموقعي واقل حجم انجراف وايضا اقل كمية ترسيب متجمعة خلف المسننات المستخدمة.

الكلمات المفتاحية : الانجراف الموقعي – المسننات – القطع الناقص – القطع المكافئ – درجة التقوس .